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(Article begins on next page)

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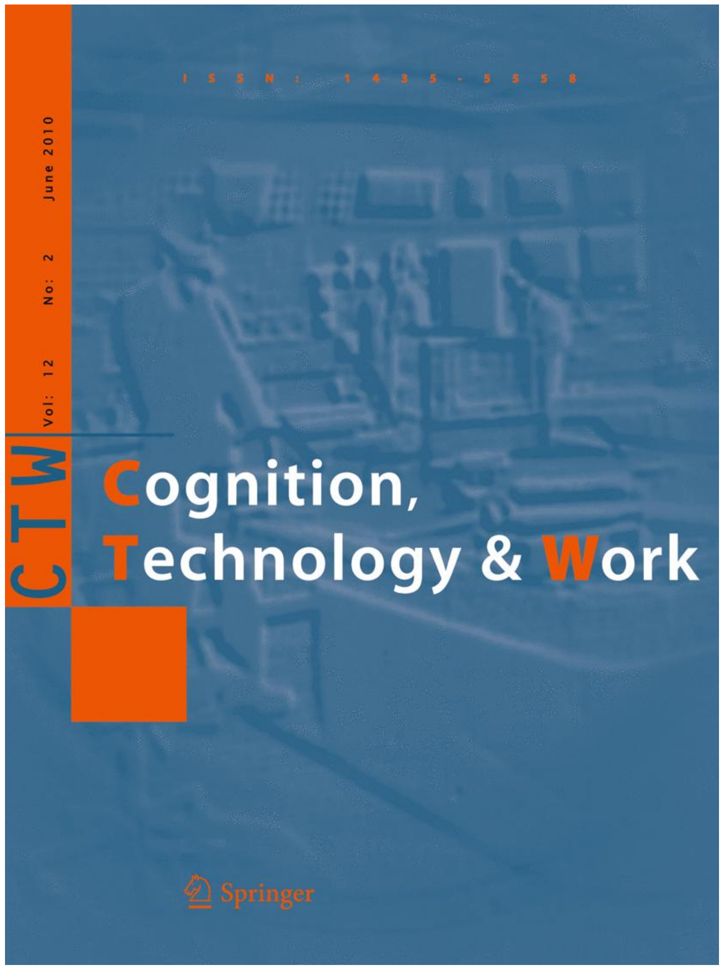

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ORIGINAL ARTICLE

From cognitive reliability to competence? An evolving approach to human factors and safety

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Abstract When reviewing the research path of an author, we are inevitably influenced by our own background and approach. Tracing back the converging and diverging assumptions of the authors with respect to Erik Hollnagel's research path, the paper focuses on the evolution of cognitive psychology as resulting from an original distinction between two models of human cognition: the first one more in line with the behaviourist tradition and the latter with the cybernetic and ecological approach. The former, which becomes dominant in the development of cognitive psychology, marginalizes some aspects that prove crucial in the latter. The concepts of anticipation and of intentional behaviour, together with the notion of variability of normal performance, are traditionally part of the cybernetic and ecological approach to cognitive psychology. These concepts have also been central in the development of the ergonomic analysis of work activities. Throughout the Resilience Engineering perspective, the two models of human cognition are brought closer, while the concept of competence is sketched as a possible mediator to a "positive" approach to Human Factors and Safety.

Keywords Human factors · Safety · Human reliability · Resilience engineering · Competence

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1 Introduction

There are researchers who develop a vast number of studies; fewer who develop a research path and even fewer whose research path develops alongside a discipline, and up to a certain extent, it influences this development. Erik Hollnagel is part of the latter. His research on Human Factors and Safety has influenced Cognitive Psychology, as well as Safety studies, where psychological and non-psychological disciplines are deeply interrelated.

The interdisciplinary character of Human Factors and Safety is discussed in the beginning of this paper to draw the context for the psychological contribution to the discipline. Both engineering and sociology required the understanding of human behaviour to ensure safety for industrial systems. Back to the 1960s, two different branches of Cognitive Psychology were available to understand and describe human behaviour. The first branch of research goes under the definition of Information Processing, where the computer was the most exploited analogy for human cognition. In this trend, it is possible to find most of the contributions Hollnagel gave from the end of 1970s until the end of the 1990s. Cognitive engineering, cognitive reliability and human errors were the key terms and the main focus of interest. While deeply implied in this research context (Hollnagel et al. 1986, Hollnagel 1993, 1998), Hollnagel constantly questioned this approach and he hinted at its limits (Hollnagel 1978, 2005).

In parallel, particularly in the Francophone and Italian tradition, a different branch of research has been developed in cognitive and organizational ergonomics. (de Terssac 1992; de Montmollin 1984, 1990; Leplat 1980, 1993; Oddone et al. 1981). Recognising the central role of the cognition–action linkage, of the intentional behaviour and of the mental modelling of the everyday interactions, this approach looked at humans as the flexible, adaptable component of industrial systems. Humans were seen as the essential component for the safe functioning of the system.

In the evolution of his personal approach, Hollnagel among others, with the Resilience Engineering (Hollnagel et al. 2006; Hollnagel et al. 2008a, b), clearly breaks with the Information Processing tradition. The pivotal concept of that tradition is somehow rejected. Humans are no longer seen as the fallible components of industrial systems; they are rather considered as the key component of socio-technical systems. It is due to their ability to locally adjust their behaviour that the safe functioning is ensured. It is probably in the ETTO (Hollnagel 2009) book that the original two psychological branches of Human Factors and Safety studies come in contact after more than 30 years of parallel development.

The positive effect of performance variability is highlighted towards the conclusion of this paper. The concept of competence is also suggested as a potential bridge between the two branches of research. Taking into consideration the role of competency can allow the development of a discipline open to assert the crucial and positive role of humans on the system safety.

Underlying Hollnagel's contribution to Safety debate, this paper wishes to pay tribute to a person whose questioning attitude has contributed—contributes and will contribute—to improve the understanding of the nature of risk and safety.

2 Human factors and safety: an interdisciplinary domain

Work and research in Human Factors and Safety is a matter of multiple disciplines cooperating towards a common objective. Engineering, occupational sociology together with cognitive psychology are the three main research domains dealing with Safety and Human Factors. To effectively tackle industrial safety, it is necessary that contributions from the three disciplines are brought together to understand and prevent risks.

After the Three Mile Island accident in 1979, the Human Factors discipline welcomed a reliable-based safety model from the engineering tradition. In the engineering domain, the predominant safety model was—and still is—based on technical reliability and functional stability, in absence of deviations and disturbances. From this perspective, humans have traditionally been considered a highly variable and therefore low-reliable component, whose operational activities to the utmost comply with norms and procedures to ensure correct and satisfactory performance. In this framework, humans are considered as mere task executors, which do not generate any additional value or knowledge. For the engineering approach, risks due to the unreliability of human behaviour have to be controlled and constrained. Unfortunately, for this approach, "Complete control [...] does not exclude that an action can be incorrectly performed. There is an underlying (or residual) variability of human performance that cannot be eliminated." (Hollnagel 1998, p. 152).

From the occupational sociology, strongly marked by Charles Perrow's theory on Normal Accidents (1984), the Safety debate inherits the awareness that risks cannot be entirely predicted and eliminated in complex and tightly coupled socio-technical systems. Residual risk is due to the emergence of undesired and unplanned interactions between system's components. While shifting the potential for failure from humans to the system, Perrow highlights the direct role of management "in preventing failures—or causing them" (1984, p. 10). The nature of risk, in Perrow's words, goes far beyond the limits and boundaries of human cognition: "Above all, I will argue, sensible living with risky systems means keeping the controversies alive, listening to the public, and recognising the essentially political nature of risk assessment. Ultimately, the issue is not risk, but power; the power to impose risks on the many for the benefit of the few". (1984, p. 306).

For both the engineering and the sociological approach, uncertainty (human and/or organisational) cannot be eluded from the technical core of a system, and therefore nor can the risks be completely eliminated. Systems where uncertainty is present are always exposed to failures (Thompson 1967).

Cognitive psychology was therefore asked to focus on the characteristics and limits of human factors. Cognitive psychologists contributed to the safety debate by either designing consistent technologies with human resources and limits or introducing barriers to reduce discretion and to mitigate risks due to unusual combinations of events (Cacciabue et al. 2000). Barriers aim to protect systems from the fallibility of humans and conversely to protect humans from the less-than-perfect predictability of the system functioning.

To better understand the evolution of Erik Hollnagel's approach and to relate it to the approach of who is writing, it is worth recalling the beginning of cognitive psychology. In our opinion, in the early sixties, two research branches outlined different models of human cognition that resulted in different approaches to Human Factors and Safety. The first one refers to studies, mainly developed by the Anglophone Human Factors community, that model humans as Information Processing Systems (Hollnagel and Woods 2005). The second branch, developed mainly in the Francophone and Italian ergonomics community, considered humans as adaptive systems that actively explore the environment and proactively adapt to it. (de Terssac 1992; de Montmollin 1984, 1990; Leplat 1980, 1993; Oddone et al. 1981).

3 Two branches of research for cognitive psychology in human factors and safety

As known, in the Human Factors and Safety debate, the Information Processing Systems (IPS) approach became dominant. The computer provided a powerful analogy, being the first technology capable of simulating the complexity of human cognition through series of linear processes. The development of the IPS paradigm went along with the theoretical definition of structural limitations of human cognition. The paradigm assumed that fallibility is part of human cognition; it is therefore unchangeable.

The notion of Cognitive Reliability (Hollnagel 1998) and the underlying Contextual Control Model (Hollnagel 1993) were consistent with this approach. Human cognition was considered as a resource interacting with contextual factors, but coming first, as far as a set of predetermined limitations and capabilities. Coherently, the context was defined as a set of factors that influence, modify and often degrade the *normal* cognitive performance.

Despite being involved in the development of this approach, Hollnagel questioned very early its assumptions.

> One prominent feature of this linear paradigm is that it is a rather passive system, which only processes the information reaching it, another that information only passes through the system in one direction. Although there is experimental evidence for several components of the system, e.g. the neural detectors, the different types of memory, etc. it is incorrectly regarded as a whole. It is incorrect precisely because no system could survive in even a slightly complicated environment, if it was only allowed to respond passively to the information which reached it. (Hollnagel 1978, p. 198).

Hollnagel's scepticism about the linearity of human cognition is entirely shared by the cybernetic branch. The most appropriate technological analogy for this branch, parallel to computer for IPS, could be the thermostat, being the first and the simplest TOTE (Test-Operate-Test-Exit) unit capable of adaptive behaviour. To be adaptable, the thermostat requires an *Image* of the world. In the Boulding's (1956) classification, the thermostat is the simplest system cyclically querying its colourless and soundless world to know the state of the single variable (i.e. the temperature) it is looking for. The research path of who is writing develops from the cybernetic branch with all its implications, which go far beyond the difference between linear and circular information processing: the Miller's (1960) analysis of auto-directed intentional behaviour and of the goal-oriented action; Neisser's (1976) priority of *schema* with respect to perceptual exploration; Gibson's (1979) concept of *vista* as prospective perception from a personal point of view. On the basis of an anthropomorphic model of humans, to quote the social psychologists Harré and Secord (1972), the cybernetic *Image* of cognition describes humans as active explorers of the world, seeking for some kinds of information while neglecting others, as if they were questioning their environment. Explaining the concept of understanding through an analysis-by-synthesis model, Hollnagel (1978) notes that the hermeneutic circle represents a specific case of this general model, which is quite different from the Information Processing approach:

> According to this model the process of understanding takes place by a reciprocal interaction between two processes, which are both normally unconscious. One process produces a guess or an expectation of what the meaning of the message could be. The other process tests this guess against the message in order to establish whether the guess and the message coincide to the extent that one can say the message is understood. All in all the process […] is identical to the structure of a TOTE, as described by Miller, Galanter and Pribram (1960). (1978, p. 202).

Further differences between the IPS and the cybernetic branches of cognitive psychology should be here mentioned.

The first difference: IPS was focused on information; cybernetic on to the concept of difference: "Information consists in differences producing a difference" (Bateson 1979, p. 135). In this view, the perception is defined as checking a gap from an expected value, rather than receiving information. It is active exploration (Neisser 1976), anticipation and detection of incongruities between the desired and the actual state (Miller 1960).

The second one: as highlighted by Hollnagel (Op. Cit), IPS is a *passive system processing only the information reaching it* at a moment in time; for the cybernetic approach, auto-regulation is a temporal process developing through the interaction of the organism with the external world: "The discrepancy between the target and the actual response decides the next response in much the same way as a golfer's error on the putting green decides his next putt" (Annett 1972, p. 10). This temporality is directed by the expectations and goals of a subject challenging an external world that offers resistance to his action: "Perception and cognitive activity usually are not simple transactions at the mental level, but transactions with the external world" (Neisser 1976, p. 35).

The third one: IPS was concerned with human reliability and human error, and variability was seen as a deviation that grows larger and larger from the core of the system; the cybernetic approach sees variability as a constitutive feature of dynamic systems (Ashby 1960, p. 79).

In our opinion, being dominant in the Human Factors and Safety debate, IPS marginalised several pivotal aspects that were independently developed in the same years by many Italian and Francophone ergonomists: *anticipation* and *goal-directed actions*.

The concept of *anticipation* (de Terssac 1992) refers to the cognitive activation humans experience while expecting an event to happen. Such activation takes place before any sensory information becomes available. This concept is barely coherent with the Information Processing paradigm, which does not account for the active search for information and for expectations used to control action, while it is quite consistent with the Neisser's (1976) "picking up information" concept.

In the ergonomic analysis of work, the concept of *goal-directed behaviour* is fundamental (Leplat 1997), as well as that of humans as action-oriented systems. Events in the everyday world are considered as favourable or unfavourable, as positive occasions or obstacles. When an obstacle prevents a goal-directed system from achieving its objective, the system tries to remove the obstacle or tries to move around it or to make the most of it (Minsky 1986).

Since 2004, at least, Hollnagel's unease with the IPS basic concepts became more formalised. In the *Barriers and Accident Prevention* book (Hollnagel 2004), the notion of human error and human reliability is substituted by the concept of performance variability. The book presented the Functional Resonance Analysis Method as a non-linear method to perform accident analysis and safety assessment. The focus of the method is variability of normal performance due to approximate adjustments.

4 Acknowledging positive effects of performance variability

The traditional approach of IPS, as previously mentioned, consisted in ensuring safety by designing and enforcing barriers to reduce the number of human errors and to mitigate their consequences, or in other terms to reduce discretion and variability. Hollnagel somehow breaks with this approach when he recognises that discretion and variability are indeed the sources for incidents and accidents, but in the normality, they are the source of successes and functioning:

> […] failures represent the flip side of the adaptations necessary to cope with the real world complexity rather than a failure of normal system functions. Success depends on the ability of organisations, groups and individuals to anticipate risks and critical situations, to recognise them in time, and to take appropriate action; failure is due to the temporary or permanent absence of that ability […] (Hollnagel et al. 2008a, b).

Diverging from the Engineering approach and the Information Processing paradigm, Hollnagel's thinking, at this stage, conceptually converges with the ergonomic research based on the analysis of work activities, where variability has always been recognised as a work domain characteristic, rather than as a human limit. The assumption is that standardised/linear performance does not exist in real work. Accelerating and delaying factors can change, but they always influence the execution time. For example, Musatti (1971) recognised that the minimum execution time, as well as the stability of the operative process, are ideal models that encumber our representation and understanding of the real world, rather than supporting us to understand it. Leplat (2000) distinguishes between *work-as-done* and *work-as-expected* to describe this situation.

In this research tradition, experienced workers are described as constantly assessing upcoming situations and anticipating possible future actions (de Montmollin 1984) both in low technological tasks, e.g. like that of party-structures installers or of traffic agents (Lacomblez et al. 2007), and in highly automated context, e.g. air traffic control (de Terssac 1992).

When variability theoretically becomes a constitutive part of the work, the analysis of interactions occurring *between* human cognition and the situations in which behaviour occurs (Hollnagel 1998, p. 31) gives place to the concept of action *as part* of the context, rather than as a dependent variable of the context (Bateson 1979, p. 374). Overcoming the concept of linear cognitive-driven performance potentially affected by shaping factors, the analysis focuses on the normal system functioning (McDonald et al. 2002).

From our point of view, clearly influenced by our background and assumptions, the notion of *Resilience* constitutes the transition point from an approach where humans are considered the weak and unreliable components of a socio-technical system to an approach where humans' contribution to the functioning and to the safety of a system is mainly positive. It is in this transition that Hollnagel's path re-establishes a connection between the two branches of cognitive psychology outlined at the beginning of this paper.

Through the critiques to performance shaping factors, the normal functioning of the system becomes the central point to better understand and manage safety. How this understanding could be actually achieved? For the ergonomic analysis of work activities, the main resilience factor consists in the expert workers' management of performance variability in working settings. The concept of activity does not merely consist of a behavioural response, rather it refers to the psychological dimension of work: "What operators produce during their activity constitutes a marginal part of that activity. The action, the act, the choice they would have liked to do, but they did not, what they are forbidden to do or they prohibit their selves from doing, what they think it is inappropriate to do or they could do if… are all moments of the activity and they all constitute a major part of it. All these possibilities remain in the subjective and collective activities as potentialities waiting to be implemented". (Clot 2006, p. 11).

Substituting the view on humans as fallible executors with the view on humans as intelligent producers of system's reliability implies the revision of the role and nature of barriers and countermeasures and, among them, of procedures. Since resilience cannot simply be ensured by the respect of rules and procedures or by the ability to recover from disturbances and to regain the normal functioning, barriers, designed as constraining elements, are no longer sufficient to make a system safe. The acknowledgement of the positive effects, beside the well-known negative ones, of variability requires the understanding of the underlying reasons for successful performance.

5 From performance variability to competence?

To be positive with the functioning and safety of industrial systems, performance variability has to be somehow successful. In his most recent book, Hollnagel (2009) introduces a trade-off principle to explain the underlying reasons for performance variability: " […] people (and organisations) as part of their activities frequently—or always—have to make a trade-off between the resources (time and effort) they spend on preparing an activity and the resources (time and effort) they spend on doing it. The trade-off may favour thoroughness over efficiency if safety and quality are the dominant concerns, and efficiency over thoroughness if throughput and output are the dominant concerns." (Hollnagel 2009, p. 29).

Activities, at both human and organisational level, are faced with a dilemma. Or people "[…] wait, to gather more information, to see how things develop, or just to hope for a greater level of certainty—or less uncertainty […]" or they "[…] go ahead on the assumption that the situation is known well enough and the alternatives are clear enough—and indeed that all reasonable alternatives are known." (Hollnagel 2009, p. 28).

This, indirectly, relies on the use of competences. In our understanding, only a competent operator can decide when it is appropriate to wait (allocating time to think about the situation) and when it is appropriate to act in the situation.

In order to ensure safety in a dynamic system, operators have to be taught not only the procedure, but also how to make use of it, which is what operators usually learn by experience. For an appropriate use of competences, procedures should therefore be considered as resources for actions provided to experienced workers. Referring to the concept of *frame* (Minsky 1986), procedures can be learned and internalised as mental structures lacking their final parts, which are to be built in relation to the actual situations. As shown by de Terssac (1992), in control rooms dealing with an incident, warning is not only a matter of more work to do, but also a matter of different work to be carried out. In absence of alarms, control room operators tend to work independently. When an abnormal situation occurs, they collaborate to produce a collective response, even when such collaboration is not prescribed by procedures. In the same way, a strategy change takes place when an operator is faced with an increasing amount of work. After a first increase in his/her activity, a different action plan is actuated (Sperandio 1980). In both cases, operators seem to have pondered about the congruity between planned action and the actual situation.

In contrast to who sees in the non-compliance of procedures the fundamental cause of human errors and accidents, we acknowledge that the lack of correspondence between procedures and work practices occurs in both accidental and non-accidental situations. This non-compliance can be observed not only in situations prior to accidents, but it is common practice in situations that do not lead to negative outcomes (Snook 2000; Woods et al. 1994). This implies that the analysis of accidents that are preceded by violations is pure tautology, since it is based on a selection of cases where the sought result is present by definition.

The relationship between competence and control constitutes a further point where the two theoretical models of cognitive psychology, and therefore Hollnagel's and our perspective, seem to take different paths. The Information Processing paradigm can separate competence and control: "I have previously (Hollnagel 1993) presented an approach to the modelling of cognition […] The basic principle in this approach was a description of competence and control as separate aspects of performance. The competence describes what a person is capable of doing, while the control describes how the competence is realised, i.e. a person's level of control over the situation. The level of control clearly depends on the situation itself, hence on the context." (Hollnagel 1998, p. 152).

In our understanding, it is as if the elementary TOTE unit (Miller 1960) were broken down, therefore it is crucial to stress the impossibility to dissociate control from competence. No control can exist without competence, and *vice versa*.

In this perspective, the analysis is no longer focused on the acute pathogen elements, i.e. the human error, nor on the chronic presence of latent failure conditions. The focus of analysis shifts on the competency-based normal performance, and how to support it. Coherently, the metaphor classically proposed for safety is no more the classical *vulnerable system syndrome* (Reason et al. 2001), but rather the analogy with Health, understood as something different from a disease-free state, or an initial asset to be secured from attacks. In this view, health is rather to be seen as a process of continuous construction, where the working activities contribute through a stronger sense of self-efficacy, as a result of social challenge and cooperation.

Thus, if the approach based on human error reduction and risk mitigation does not adequately account for the importance of operational safety building processes, the concept of *competence* can account for a positive view on human factors and safety.

6 Conclusions

This paper sketched the evolving approach of Hollnagel, as representative of a broader theoretical development of the studies about Human Factors and Safety. Starting within the Information Processing paradigm, Hollnagel's research path seems to highlight an evolution from the concept of *response* to a concept of *intentionality;* from implementing *barriers* to *building* safety; from modelling *human cognition* to understanding the *resilience* of a system; from the concept of *reliability* to the concept of *variability*.

It seems that acknowledging the intentionality, the proactivity and the variability of human performance would require accounting for operators' competence. Despite, once again in our understanding, *competence* is the underlying factor influencing the way in which Efficiency-Thoroughness Trade-Off takes place, Hollnagel does not (yet) explicitly refer to it.

Nevertheless, competence comes to light whenever we move from the notion of cognitive reliability to the central role of performance variability in ensuring the safe functioning of any complex socio-technical system.

The role of competences is well documented, for example, in aviation maintenance, i.e. a highly regulated domain. Several works describe how mechanics see successful activities resulting from their ability to learn, to adapt, to invent, to improvise and to find the right trade-off facing pressures, demands, organisational contradictions and lack of resources (McDonald et al. 2002; Van Avermaete and Hakkeling-Mesland 2001). The same is true for Air Traffic Controllers who pride themselves in their skills and understanding of rules and procedures to deliver the best service to their clients (EUROCONTROL 2009).

A concluding question is addressed to ourselves: is our understanding of Hollnagel's research path actually correct? Two episodes suggest it could be. The first, during a European project meeting, after hours spent in discussing failures and human errors, one among us could not restrain himself from saying: "To improve safety, the concept of human error is inadequate. Operators are the positive component of a system, it would be more relevant to study workers' operational and social contribution to safety". Erik Hollnagel simply replied: "I could not agree more".

The second episode took place during a cocktail-buffet of an International conference. Once again discussions during the conference were mainly focused on failures, human errors, enforcing barriers and the like. To someone's disappointment with these traditional topics and to the rhetoric question if something will ever change, Prof. Hollnagel replied: "It is 20 (maybe 30 A/N) years that I have been arguing for a change in perspective. Who knows that, one day, this will happen…".

In conclusion, still wondering to what extent we are right in our understanding of the thinking and work of Erik Hollnagel, while identifying in an unilateral way synergies and divergences from our approach, we take comfort in Gregory Bateson's (1979, p. 26) words: "Those who lack all idea that it is possible to be wrong can learn nothing, except know-how".

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